

Strong-interaction shifts and widths of kaonic helium isotopes

SIDDHARTA Collaboration

T. Ishiwatari ^{a,*}, M. Bazzi ^b, G. Beer ^c, L. Bombelli ^d,
A.M. Bragadireanu ^{b,e}, M. Cargnelli ^a, C. Curceanu (Petrascu) ^b,
A. d’Uffizi ^b, C. Fiorini ^d, T. Frizzi ^d, F. Ghio ^f, C. Guaraldo ^b,
R.S. Hayano ^g, M. Iliescu ^{b,e}, M. Iwasaki ^h, P. Kienle ⁱ, P. Levi Sandri ^b,
A. Longoni ^d, J. Marton ^a, S. Okada ^h, D. Pietreanu ^{b,e}, T. Ponta ^e,
A. Rizzo ^b, A. Romero Vidal ^b, E. Sbardella ^b, A. Scordo ^b, H. Shi ^g,
D.L. Sirghi ^{b,e}, F. Sirghi ^{b,e}, H. Tatsuno ^b, A. Tudorache ^e, V. Tudorache ^e,
O. Vazquez Doce ⁱ, E. Widmann ^a, B. Wünschek ^a, J. Zmeskal ^a

^a Stefan-Meyer-Institut für subatomare Physik, Vienna, Austria

^b INFN, Laboratori Nazionali di Frascati, Frascati (Roma), Italy

^c Dep. of Phys. and Astro., Univ. of Victoria, Victoria B.C., Canada

^d Politechno di Milano, Sez. di Elettronica, Milano, Italy

^e IFIN-HH, Magurele, Bucharest, Romania

^f INFN Sez. di Roma I and Inst. Superiore di Sanita, Roma, Italy

^g Univ. of Tokyo, Tokyo, Japan

^h RIKEN, The Inst. of Phys. and Chem. Research, Saitama, Japan


ⁱ Tech. Univ. München, Physik Dep., Garching, Germany

Received 8 November 2012; received in revised form 27 November 2012; accepted 7 December 2012

Available online 10 December 2012

Abstract

tion and similar papers at core.ac.uk

brought to you by  CORE

provided by Elsevier - Publisher Connector

SIDDHARTA

Experiment. The K^+K^- energies of these transitions were measured with large DAΦNE e^+e^- detectors using the timing information of the K^+K^- pairs produced by the DAΦNE e^+e^- collider. The strong-interaction shifts and widths both of the kaonic ^3He and ^4He $2p$ states were determined, which are much

* Corresponding author.

E-mail address: tomoichi.ishiwatari@assoc.oaw.ac.at (T. Ishiwatari).

smaller than the results obtained by the previous experiments. The “kaonic helium puzzle” (a discrepancy between theory and experiment) was now resolved.

© 2012 Elsevier B.V. Open access under [CC BY-NC-ND license](#).

Keywords: Exotic atoms; Kaonic helium; Silicon-drift detectors; Strong interaction

1. Introduction

The X-ray spectroscopy of the kaonic helium isotopes (^3He and ^4He) plays an important role for understanding low-energy QCD in the strangeness sector. Low-lying energy levels of kaonic atoms are shifted and broadened due to the strong interaction between the antikaon and helium. Thus, the measurements of the X-ray energy shifts and widths provide fundamental information on the strong interaction at the low-energy regime.

The X-ray measurements of kaonic ^4He atoms performed in the 70s and 80s [1–3] introduced a serious problem; *i.e.*, inconsistency between theory and experiment both in the shift and width of the kaonic ^4He $2p$ state.

The shift measured in the 70s and 80s was -43 ± 8 eV on average [3,4], whereas theoretical calculations gave a shift below 1 eV based on the kaonic atom data with the atomic numbers $Z \geq 3$ [3–6]. The widths of $\Gamma_{2p} = 1\text{--}2$ eV was theoretically estimated both for kaonic ^3He [6] and ^4He [3–6]. Experimentally, however, the width of kaonic ^4He was not well determined, leaving the situation unclear. The results of $\Gamma_{2p} = 30 \pm 30$ eV [2], and 100 ± 40 eV [3], with an average of 55 ± 34 eV were reported, along with the following comment on their results [3]. “The shift measurements are seen to be in good agreement. The situation for the width values is much less satisfactory and the error bars of the two measured values do not overlap. The error on the quoted average has been taken from the external variance of the measured values.”

The discrepancy of the shift and width between theory and experiment is known as the “kaonic helium puzzle”. Possible shifts up to 10 eV and widths up to 40 eV either in kaonic ^3He or ^4He were calculated related to the kaonic nuclear systems [7]. Therefore, it is very important to perform a precision measurement of the shift and width of the kaonic ^4He $2p$ state, and for the first time of kaonic ^3He .

2. The SIDDHARTA experiment

The kaonic helium X-rays were measured in the framework of the SIDDHARTA experiment [8–10]. The SIDDHARTA experiment used low-energy kaons generated by the DAΦNE electron–positron collider, which could be stopped efficiently in a small volume of gaseous targets.

K^+K^- pairs produced by ϕ decay were detected by two scintillators installed above and below the beam pipe at the interaction point. The coincidence signals of the K^+K^- pairs were used for the timing selection of the X-ray events. Above the upper scintillator, degraders were installed to degrade the kaon energy so that the K^- mesons were stopped in the target gas volume. Cryogenic helium gas at 1 bar and 20 K was used as a target. The cylindrical target cell was made of Kapton foils. In the top of the cell, thin Ti and Cu foils were installed for the energy calibration. Large-area silicon-drift detectors (SDDs) having an active area of 1 cm^2 each and a thickness of $450\text{ }\mu\text{m}$ were used for X-ray detection [11]. A total active area of 144 cm^2 was installed. The SDDs were cooled to a temperature of 170 K with a stability of ± 0.5 K.

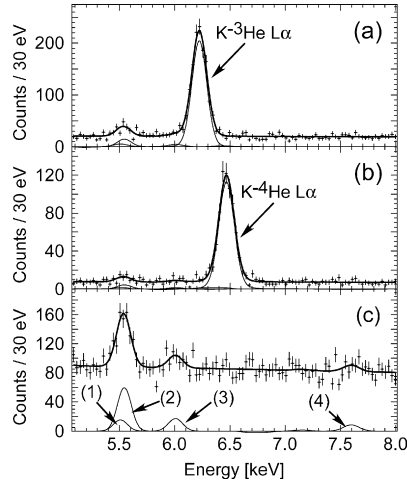


Fig. 1. X-ray energy spectra of (a) kaonic ${}^3\text{He}$, (b) kaonic ${}^4\text{He}$, and (c) kaonic deuterium. The positions of the kaonic ${}^3\text{He}$ and ${}^4\text{He}$ $3d \rightarrow 2p$ transitions are indicated. In (c), (1): $K^- \text{C} 6 \rightarrow 5$ transition, (2): $K^- \text{C} 8 \rightarrow 6$ transition, (3): $K^- \text{O} 7 \rightarrow 6$ transition, and (4): $K^- \text{N} 6 \rightarrow 5$ transition.

The main background source at DAΦNE were charged particles scattered from the beams which were uncorrelated to the K^+K^- coincidence. Thus, event selections could suppress this background using the timing information of the K^+K^- coincidence in the scintillators and the X-ray hits on the SDDs.

3. Data analysis

The calibration data were taken every several hours, by inserting Ti and Cu foils and an X-ray tube below the setup to increase the X-ray production rates. The energy scale of the X-ray data was calibrated for each SDD using the peak positions of the Ti $K\alpha$ (4.5 keV) and the Cu $K\alpha$ (8.0 keV) lines. The data were selected for further analysis in terms of stability, energy resolution and the X-ray peak shapes.

The accuracy of the energy scale was examined using the Ti $K\alpha$ (4.5 keV), Cu $K\alpha$ (8.0 keV), and Au $L\alpha$ (9.6 keV) lines in the energy spectra uncorrelated to the kaon timing. The peak positions were shifted by about 6 eV, because of the different hit rates induced by the X-ray tube radiation in the calibration data [9]. This peak shift was corrected. From the fit of these X-ray peaks, the uncertainty of the energy determination was found to be ± 4 eV, and the uncertainty of the detector resolution σ was ± 2 eV at 6-keV X-rays.

The X-ray events with the timing of the K^+K^- pairs were selected to produce the energy spectra of kaonic helium with good signal-to-background ratios. The energy spectra of the kaonic ${}^3\text{He}$ and ${}^4\text{He}$ X-rays are shown in Figs. 1(a) and (b), where the thin lines show the peak fit functions after the background subtraction. The peaks at 6.2 keV and 6.4 keV are the kaonic ${}^3\text{He}$ and ${}^4\text{He}$ $3d \rightarrow 2p$ transitions, respectively. Fig. 1(c) shows the X-ray energy spectrum using the deuterium target, where the signals of the kaonic deuterium X-rays are not visible. This energy spectrum was used for the extraction of the background shapes.

In addition to kaonic helium, several small peaks were observed in all the spectra, which originated from the kaonic atom X-rays produced in the target window material made of Kapton Polyimide ($\text{C}_{22}\text{H}_{10}\text{N}_2\text{O}_5$), since some kaons were stopped there. The X-ray peaks at 5.5, 6.0,

Table 1

Energy shifts (ΔE_{2p}) and widths (Γ_{2p}) of the kaonic helium ^3He and ^4He $2p$ states.

Target	ΔE_{2p} (eV)	Γ_{2p} (eV)	Ref.
^4He	-41 ± 33	–	Wiegand et al. [1]
^4He	-35 ± 12	30 ± 30	Batty et al. [2]
^4He	-50 ± 12	100 ± 40	Baird et al. [3]
^4He	-43 ± 8	55 ± 34	Average of above [3,4]
^4He	$+2 \pm 2$ (stat.) ± 2 (syst.)	–	Okada et al. [12]
^4He	0 ± 6 (stat.) ± 2 (syst.)	–	SIDDHARTA [8]
^4He	$+5 \pm 3$ (stat.) ± 4 (syst.)	14 ± 8 (stat.) ± 5 (syst.)	SIDDHARTA [9,10]
^3He	-2 ± 2 (stat.) ± 4 (syst.)	6 ± 6 (stat.) ± 7 (syst.)	SIDDHARTA [9,10]

and 7.6 keV are the kaonic carbon (K^-C) $6 \rightarrow 5$, oxygen (K^-O) $7 \rightarrow 6$, and nitrogen (K^-N) $6 \rightarrow 5$ transitions, respectively. The kaonic ^3He X-ray peak partially overlapped with the K^-O transition. The contamination of this transition was evaluated using the kaonic deuterium data. The energy spectra were fitted using a Voigt function: $V = V(\sigma, \Gamma)$, where Γ represents the strong-interaction $2p$ width. Due to the strong parameter correlation between the values of σ and Γ in the fit, the values of σ were fixed using the values obtained from the calibration data. The main contribution to the systematic errors for the widths of Γ is related to the uncertainty in the values of σ [10]. The determined shift and width of the kaonic helium $2p$ states are summarized in Table 1, together with the results of the previous experiments.

4. Conclusions

In conclusion, the strong-interaction shifts and widths both of the kaonic ^3He and ^4He $2p$ states were measured by the SIDDHARTA experiment, where kaonic ^3He was measured for the first time. Both the shift and width of kaonic ^4He were found to be much smaller than the values determined in the 70s and 80s [3,4], while the shift is in good agreement with the results of [12]. The strong-interaction shifts and widths of the kaonic ^3He and ^4He $2p$ levels are in agreement with the theoretical estimated values [3–6]. No abnormally large shifts or widths were found either in kaonic ^3He or ^4He .

Acknowledgements

Part of this work was supported by HadronPhysics I3 FP6 European Community program, Contract No. RII3-CT-2004-506078; HadronPhysics 2, Grant Agreement No. 227431, and HadronPhysics 3, Contract No. 283286 under the Seventh Framework Programme of EU; Austrian Federal Ministry of Science and Research BMBWK 650962/0001 VI/2/2009; Romanian National Authority for Scientific Research, Contract No. 2-CeX 06-11-11/2006; the Grant-in-Aid for Specially Promoted Research (20002003), MEXT, Japan; the Austrian Science Fund (FWF): [P20651-N20]; and the DFG Excellence Cluster Universe of the Technische Universität München.

References

- [1] C.E. Wiegand, R. Pehl, Phys. Rev. Lett. 27 (1971) 1410.

- [2] C.J. Batty, et al., Nucl. Phys. A 326 (1979) 455.
- [3] S. Baird, et al., Nucl. Phys. A 392 (1983) 297.
- [4] C.J. Batty, Nucl. Phys. A 508 (1990) 89c.
- [5] DEAR Collaboration, S. Bianco, et al., Riv. Nuovo Cimento 22 (1999) 1.
- [6] E. Friedman, Hyperfine Interact. 209 (2012) 127, arXiv:1111.7194v1 [nucl-th].
- [7] Y. Akaishi, in: Proc. Inter. Conf. on Exotic Atoms (EXA05), <http://dx.doi.org/10.1553/exa05s45>.
- [8] SIDDHARTA Collaboration, Phys. Lett. B 681 (2009) 310.
- [9] SIDDHARTA Collaboration, Phys. Lett. B 697 (2011) 199.
- [10] SIDDHARTA Collaboration, Phys. Lett. B 714 (2012) 40.
- [11] M. Bazzi, et al., Nucl. Instrum. Methods A 628 (2011) 264.
- [12] S. Okada, et al., Phys. Lett. B 653 (2007) 387.